Practice Exam for Exam 3

1. (15 points) Calculate the ***boiling point*** of water at 2.500 bar.

The normal boiling point of water is 100.0°C (pressure = 1.000 atm = 1.013 bar)

$$\ln\frac{p_2}{p_1} = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\frac{R\ln\frac{p_2}{p_1}}{\Delta H_{vap}} + \frac{1}{T_2} = \frac{1}{T_1}$$

$$= \frac{\left(8.3145 \text{ J mol}^{-1}\text{ K}^{-1}\right)\ln\frac{1.013 \text{ bar}}{2.500 \text{ bar}}}{\left(40.9\times10^3 \text{ J mol}^{-1}\right)} + \frac{1}{373.15 \text{ K}}$$

$$= 2.496241\times10^{-3} \text{ K}$$

$$\text{T}_1 = 401 \text{ K} = 127 \ ^\circ\text{C}$$

2. (15 points) I have created a new element in my garage that I am calling Milliganium (Ml). The density of this element is 25.96 g/mL. Chemical tests indicate that the atomic mass of this element is 312.3 amu. X-ray diffraction data indicate that the edge length of the unit cell is 341.9 pm. What is the ***type of unit cell*** does this element use? What is the ***radius*** of the atom in pm?

$$?\frac{\text{atom}}{\text{cell}} = \frac{(341.9 \text{ pm})^3}{\text{cell}} \times \left(\frac{10^{-12} \text{ m}}{1 \text{ pm}}\right)^3 \times \left(\frac{1 \text{ cm}}{10^{-2} \text{ m}}\right)^3 \times \frac{1 \text{ mL}}{1 \text{ cm}^3} \times \frac{25.96 \text{ g}}{1 \text{ mL}}$$

$$\times \frac{6.022\times10^{23} \text{ amu}}{1 \text{ g}} \times \frac{1 \text{ atom}}{312.3 \text{ amu}} = 2.00 \text{ atom/cell}$$

The unit cell is body-centered cubic. The radius of the atom is:

$$e = \frac{4r}{\sqrt{2}} \Rightarrow r = \frac{\sqrt{2}e}{4} = \frac{\sqrt{2}(341.9 \text{ pm})}{4} = 120.9 \text{ pm}$$

3. (16 points) Four ice cubes at exactly 0°C with a total mass of 53.5 g are combined with 115 g of water at 75°C in an insulated container. If no heat is lost to the surroundings, what is the ***final temperature*** of the mixture?

$$q_{ice} = -q_{H_2O}$$

$$n_{ice}\Delta H_{fus} + m_{ice}s_{H_2O}\left(T_f - T_{i,ice}\right) = -m_{H_2O}s_{H_2O}\left(T_f - T_{i,H_2O}\right)$$

$$n_{ice}\Delta H_{fus} + m_{ice}s_{H_2O}T_f - m_{ice}s_{H_2O}T_{i,ice} = -m_{H_2O}s_{H_2O}T_f + m_{H_2O}s_{H_2O}T_{i,H_2O}$$

$$n_{ice}\Delta H_{fus} - m_{H_2O}s_{H_2O}T_{i,H_2O} - m_{ice}s_{H_2O}T_{i,ice} = -m_{H_2O}s_{H_2O}T_f - m_{ice}s_{H_2O}T_f = T_f\left(-m_{H_2O}s_{H_2O} - m_{ice}s_{H_2O}\right)$$

$$\frac{n_{ice}\Delta H_{fus} - m_{H_2O}s_{H_2O}T_{i,H_2O} - m_{ice}s_{H_2O}T_{i,ice}}{\left(-m_{H_2O}s_{H_2O} - m_{ice}s_{H_2O}\right)} = T_f$$

$$= \frac{\left[(53.5\text{ g})\left(\frac{1\text{ mol}}{18.0153\text{ g}}\right)\right](6.01\text{ kJ mol}^{-1})\left(\frac{10^3\text{ J}}{1\text{ kJ}}\right) - (115\text{ g})(4.184\text{ J g}^{-1}\,{}^\circ\text{C}^{-1})(75^\circ\text{C}) - (53.5\text{ g})(4.184\text{ J g}^{-1}\,{}^\circ\text{C}^{-1})(0^\circ\text{C})}{\left(-(115\text{ g})(4.184\text{ J g}^{-1}\,{}^\circ\text{C}^{-1}) - (53.5\text{ g})(4.184\text{ J g}^{-1}\,{}^\circ\text{C}^{-1})\right)}$$

$$= 25.87^\circ\text{C} = 25.9^\circ\text{C}$$

4. (19 points) A solution is made by combining 22.5 mL of Benzene (density = 0.8765 g/mL, molar mass = 78.11 g/mol) and 83.5 mL of Propyl Chloride (density = 0.8909 g/mL, molar mass = 78.54 g/mol). Assume the volumes are additive. The vapor pressures of these two liquids are 94.61 mmHg and 337.9 mmHg, respectively. Calculate the ***mole fraction of each component*** of the solution. Calculate the ***mole fraction of the solute*** in the vapor above the solution.

$$X_{benzene} = \frac{n_{benzene}}{n_{total}} = \frac{22.5\text{ mL} \times \frac{0.8765\text{ g}}{\text{mL}} \times \frac{1\text{ mol}}{78.11\text{ g}}}{\left(22.5\text{ mL} \times \frac{0.8765\text{ g}}{\text{mL}} \times \frac{1\text{ mol}}{78.11\text{ g}}\right) + \left(83.5\text{ mL} \times \frac{0.8909\text{ g}}{\text{mL}} \times \frac{1\text{ mol}}{78.54\text{ g}}\right)} = 0.210$$

$$X_{propyl} = 1 - X_{benzene} = 0.790$$

$$P_{vapor} = X_{benzene}P^\circ_{benzene} + X_{propyl}P^\circ_{propyl} = (0.210)(94.61\text{ mmHg}) + (0.790)(337.9\text{ mmHg}) = 289\text{ mmHg}$$

$$X_{benzene,vap} = \frac{P_{benzene,vap}}{P_{vapor}} = \frac{X_{benzene}P^\circ_{benzene}}{P_{vapor}} = \frac{(0.210)(94.61\text{ mmHg})}{289\text{ mmHg}} = 0.0687$$

5. (15 points) 425 g of a protein are dissolved into enough water to make 100.0 mL of solution. If the osmotic pressure of this solution is 0.726 bar at 35.2°C, what is the ***molar mass*** of the protein? (Proteins are molecular substances)

$$\Pi = MRT = \left(\frac{\text{mol solute}}{\text{L solution}}\right)RT = \left(\frac{\text{mass solute}}{\text{L solution} \times \text{molar mass}}\right)RT$$

$$\text{molar mass} = \left(\frac{\text{mass solute}}{\text{L solution} \times \Pi}\right)RT$$

$$= \left(\frac{425\text{ g}}{100.0\text{ mL} \times \frac{10^{-3}\text{ L}}{1\text{ mL}} \times 0.726\text{ bar}}\right)\left(0.083145\text{ L bar mol}^{-1}\text{ K}^{-1}\right)\left(308.4\text{ K}\right) = 1.50 \times 10^{5}\text{ g mol}^{-1}$$

6. (20 points) You are given a 0.4563-m solution of glucose ($C_6H_{12}O_6$) which has a density of 1.315 g/mL? Determine the ***molar concentration*** of the solution. (Hint: it is NOT 0.4563 M!) Calculate the ***melting point***, ***boiling point*** and ***osmotic pressure*** in bar of this solution at 31.4 °C. Use 2 decimal places for the unchanged melting and boiling points.

$$\text{assume 1.0000 kg solvent} \therefore 0.4563\text{ mol glucose} \times \frac{180.15\text{ g } C_6H_{12}O_6}{1\text{ mol } C_6H_{12}O_6} = 82.2\underline{0}2\text{ g } C_6H_{12}O_6$$

$$\text{mass of solution} = 1.0000 \times 10^{3}\text{ g} + 82.2\underline{0}2\text{ g } C_6H_{12}O_6 = 1082.\underline{2}0\text{ g solution}$$

$$\text{volume of solution} = 1082.\underline{2}0\text{ g solution} \times \frac{1\text{ mL}}{1.315\text{ g}} \times \frac{10^{-3}\text{ L}}{1\text{ mL}} = 0.8230\text{ L}$$

$$\text{molarity} = \frac{0.4563\text{ mol}}{0.8230\text{ L}} = 0.5545\text{ M}$$

$$\Delta T_f = -K_f mi = -\left(1.858\ ^{\circ}\text{C m}^{-1}\right)\left(0.4563\text{ m}\right)\left(1\right) = -0.8478\ ^{\circ}\text{C}$$

$$T_f' = T_f^{\circ} + \Delta T_f = 0.00\ ^{\circ}\text{C} + \left(-0.8478\ ^{\circ}\text{C}\right) = -0.85\ ^{\circ}\text{C}$$

$$\Delta T_b = K_b mi = \left(0.512\ ^{\circ}\text{C m}^{-1}\right)\left(0.4563\text{ m}\right)\left(1\right) = 0.234\ ^{\circ}\text{C}$$

$$T_b' = T_b^{\circ} + \Delta T_b = 100.00\ ^{\circ}\text{C} + \left(0.234\ ^{\circ}\text{C}\right) = 100.23\ ^{\circ}\text{C}$$

$$\Pi = MRT = \left(0.5545\text{ M}\right)\left(0.083145\text{ L bar mol}^{-1}\text{ K}^{-1}\right)\left(304.6\text{ K}\right) = 14.04\text{ bar}$$